Turbo-Like Codes for Space Applications *

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Motivated by the need for low-complexity, high-performance coding systems for space applications, we discuss how to improve the structure and the component codes of turbo-like codes using iterative decoding analysis. The objective is to reduce the required signal-to-noise ratio for a practical range of bit and word error probabilities. A "density evolution" method is used to analyze the performance and optimize the structure of turbo-like codes. We view the evolution of the density function of extrinsics through the iterative decoding of turbo-like codes as a non-linear dynamical system with feedback. Iterative decoding of turbo codes and serially concatenated codes is first analyzed based on this method for large block size. Then the analysis is generalized to serial concatenations of mixtures of different outer and inner constituent codes. Design examples are given to optimize mixture codes and components to achieve low iterative decoding thresholds on signal-to-noise ratio.

We analyze turbo-like codes by using the density functions for the extrinsics, and then computing their mean and variance during the density function evolution. We also consider approximating these density functions by Gaussian density [1], [3] to obtain a threshold on minimum bit signal-to-noise ratio E_b/N_0 for turbo-like codes. First we determine the input and output densities of the individual soft-input soft-output (SISO) modules [2] by simulation. For concatenated codes with two component codes such as parallel and serial turbo codes, we can plot the output SNR (SNR is defined as the square of the mean over the variance) versus the input SNR for one component decoder, and the input SNR versus the output SNR for the other component decoder, as shown in Fig. 1. These curves represent the SNR transfer function for the component codes using SISO. If the two curves do not cross, then the iterative decoder converges.

Using this density evolution analysis we discovered specific strengths and weaknesses of the SNR transfer function behavior of component codes. We then developed a remedial method, which improves the overall code performance by employing "mixture-codes" for the inner and/or outer component codes. A mixing operation consists of using different codes, in specified proportions, to encode sub-streams of the data stream.

This idea led us to discover combinations of constituent codes whose individual strengths and weaknesses complement each other. Turbo-like concatenated codes can then be constructed, using

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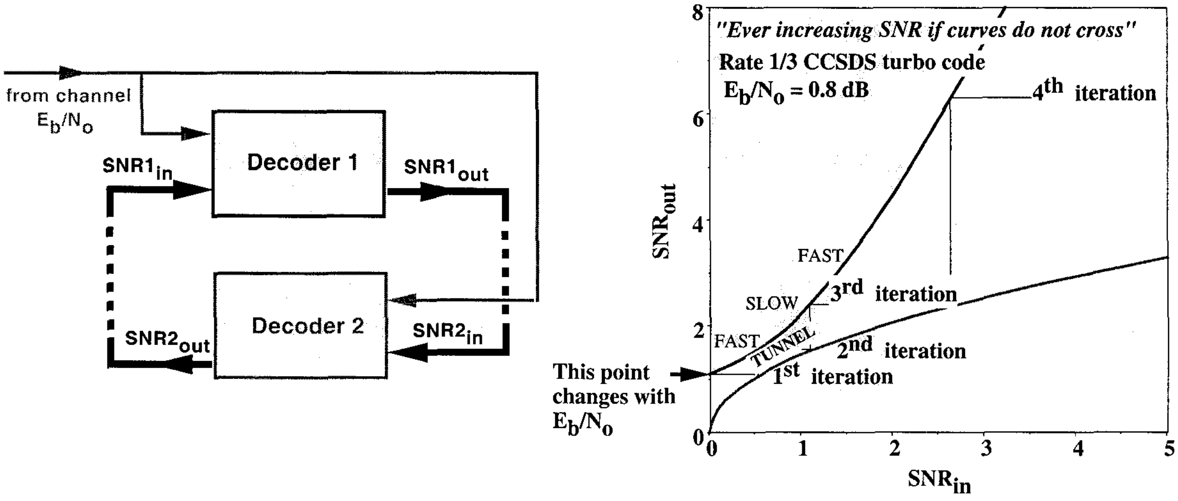

(a) (b)

Figure 1: (a) Analysis of iterative decoding as a nonlinear dynamical system using density evolution,(b) SNR transfer functions.

a mixture of such complementary constituent codes, that outperform codes formed from either constituent alone. We constructed preliminary examples using the mixture concept on low-complexity turbo-like codes, where the improvement is greater than 0.5 dB, and we expect even higher gains with optimized mixtures.

In general, such mixtures allow us to design better constituent codes that exhibit more of the strengths and fewer of the weaknesses of the individual components of the mix. The input-output SNR analysis method was crucial in providing a simple graphical insight on how to choose mixture components that complement each other. Our examples of simple rate-1/2 and rate-1/3 mixture configurations, using component codes with at most four states, approach their respective capacity limits within 0.3 dB to 0.5 dB, for very large block sizes.

References

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